

FLIGHT AND LABORATORY TESTING OF A  
DOUBLE SIDEBAND FM TELEMETRY SYSTEM

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ABSTRACT

This paper presents the findings of laboratory and preliminary flight testing of a double sideband suppressed carrier telemetry system at the NASA Flight Research Center, Edwards, California. Accuracy under environmental conditions, phase shift, and signal-to-noise ratios of the system are discussed, and a comparison is made between the use of an RF link and recording the data on magnetic tape. Preflight procedures and long-term accuracy between system adjustments are also discussed.

## SUMMARY

This paper discusses the NASA Flight Research Center's laboratory and preliminary flight evaluation of a double sideband suppressed carrier constant-bandwidth telemetry system that will be used as an airborne high-frequency data recorder. Some practical limitations are illustrated, and laboratory and flight-test results are compared. No attempt is made to compare this system with systems using other forms of modulation.

Results obtained using an RF link are compared with magnetic tape recording of data. Calibration requirements are included for each system.

## INTRODUCTION

The airborne data-gathering telemetry systems that have been used for many years at the NASA Flight Research Center are types that have low channel capability for high-frequency response. Planned flight-test research programs at the Flight Research Center will require a large number of high-frequency-response data channels. The telemetry system for these programs will have to be capable of gathering the high-frequency data accurately with as many channels as possible and using as little baseband as possible. Furthermore, the system will have to withstand the vibration and temperature environment to be encountered onboard the test aircraft in flight.

A double sideband suppressed carrier telemetry (DSB) system showed promise in meeting these requirements. Subsequently, several units of a first-generation system were procured and subjected to laboratory tests. In addition, preliminary flight tests of the system onboard a T-33 and an F-111 jet aircraft were conducted. This paper presents results of the laboratory and flight tests of the DSB system.

## SYSTEM DESCRIPTION AND OPERATION

The double sideband system contains facilities for distributing, monitoring, and demodulating telemetry signals in real time or playback mode. This system has the capability of operating with four different bandwidths: 1 kHz, 2 kHz, 4 kHz, and 8 kHz. (The Flight Research Center did not purchase 8 kHz bandwidth channels.) Twenty channels are available with the 1 kHz or 2 kHz bandwidths, 10 channels with the 4 kHz bandwidth, and 5 channels with the 8 kHz bandwidth. A mixture of the 1 kHz, 2 kHz, 4 kHz, and 8 kHz bandwidth channels can be accomplished. The frequencies associated with the 20 channels for the 1 kHz bandwidth are as follows:

<u>Channel number</u>	<u>Channel frequency, kHz</u>	<u>Channel number</u>	<u>Channel frequency, kHz</u>
1	12	11	52
2	16	12	56
3	20	13	60
4	24	14	64
5	28	15	68
6	32	16	72
7	36	17	76
8	40	18	80
9	44	19	84
10	48	20	88

An example of frequency spectrum before and after modulation by the DSB system is shown in figure 1. Figure 1(a) shows the data spectrum before modulation, and figure 1(b) shows the same data after modulation. Data signals (fig. 1(a)) are multiplied by the subcarrier frequency, thereby translating the data to the subcarrier frequency sidebands with a suppressed carrier. Steady-state (zero frequency or dc) data are translated and appear as an apparent subcarrier frequency (fig. 2, channels 5, 19, and 20). Figure 2 shows how the 20 channels of information with 1 kHz bandwidth are spaced into the bandband (channel 1 has the data of fig. 1(b)).

A block diagram of the DSB system is shown in figure 3. Figure 3(a) represents the method of adding the data, master, and pilot tones to the composite (DSB) output signal in the airborne unit. The data and pilot tones are summed and chopped at the subcarrier frequency rate. The resulting DSB signal is then summed with all other channel signals as well as the master tone. The composite signal spectrum represented in figure 2 is thereby generated.

Figure 3(b) represents the method of demodulating the composite signal in the DSB ground-station system. The master AGC (automatic gain control) is used to maintain a nearly constant composite signal to all channels. The channel band-pass filter isolates the channel DSB signal from the composite signal. This channel DSB signal is then used to recover the subcarrier center frequency for demodulation. In addition, the channel DSB signal is demodulated and filtered to recover the data and pilot tone. The demodulated pilot tone is used in the channel AGC circuit to calibrate the channel DSB signal. When the ground station recovers a signal, the signal may be  $180^\circ$  out of phase with the input signal. Correct data polarity is determined by comparing the amplitudes between the master and the channel pilot tones. A difference in amplitude of 6 decibels or greater is detected by the comparator circuit as a phase reversal. When this condition exists, the comparator circuit generates a signal that triggers a flip-flop to correct the out-of-phase condition.

The DSB airborne unit is 11 by 3-1/2 by 10 inches and weighs 15 pounds. The ground-station demodulator occupies a standard 19-inch rack and is 6 feet high.

## LABORATORY TESTS

Laboratory tests were used to determine the characteristics of the system as well as the best operational techniques.

Response Characteristics.— The phase versus frequency plot of figure 4 shows that there is a nearly constant phase shift of the signals from the system. The 1 kHz bandwidth has approximately 1 millisecond of delay, the 2 kHz bandwidth channel shows a 0.5 millisecond delay, and the 4 kHz bandwidth channel shows a delay of 0.25 millisecond.

Output filters are required in this system to aid in noise suppression and to remove the channel tones from the data. The channel frequency response is limited by the characteristics of the output filter. The frequency response of each type of channel is shown in figure 5. The responses of these filters are compromises between constant-delay and constant-amplitude filters. A constant-amplitude filter is suitable for use with sinusoidal data such as flutter; however, a constant-delay filter is desirable for use with transient data. The compromise filters were required since it was not known what type of data would be encoded by the DSB system.

Intermodulation.— Intermodulation was measured by mixing two data frequencies at the airborne-system input and measuring the amplitude of the resulting sum and difference frequency in the channel's output at the ground station. The resulting intermodulation was 0.04 percent of the full-scale input. Since this value was negligible for the Flight Research Center application, it was not tested under flight conditions.

## NOISE

The noise under hard-wire conditions was 46 decibels below a full-scale signal on all channels. This value was measured as a peak-to-peak signal versus the root-mean-square noise (signal-to-noise ratio (SNR)). Amplitude-modulated noise that occurred on the composite signal which was below 85 Hz was suppressed by the master AGC.

Radio-Frequency (RF) Link Noise.— When the system was operated with an RF link, the SNR was 35 decibels. The receiver's "IF" (intermediate frequency) SNR was set to 20 decibels with a 500 kHz "IF" bandwidth. This condition was the most adverse anticipated during an RF transmission from the airborne system.

Magnetic-Tape-Induced Noise.— Noise conditions when recording on magnetic tape vary with the recording technique. When a predetection (high-frequency response, FM type) recorder was used the SNR was 46 decibels, the same level as when the DSB system was operated hard-wired.

Direct-recorded-type magnetic-tape recording of DSB signals suffered degradation primarily because of additive noise, dropout, intermodulation, and flutter. If the phase-lock loop used for subcarrier recovery is sufficiently wide to track the time-base error (flutter), this effect is eliminated<sup>1</sup>. However, widening the phase-lock-loop bandwidths to track flutter results in noise.

Tape-Recorder Compatibility.— The Flight Research Center used an airborne tape recorder with a tape speed of 30 inches per second. This tape recorder had an amplitude response of  $\pm 3$  decibels from recorded frequencies of 100 Hz to 125 kHz. The SNR of the tape-recorder playback with shorted input (when recorded) was 30 decibels. In addition, this tape recorder exhibited a 0.5 percent peak-to-peak accumulative flutter. The subcarrier shift, as a result of tape-recorder flutter, was  $(0.005) \times (f_c)$ , where  $f_c$  is the subcarrier frequency. Consequently, the highest subcarrier frequency channel required the widest phase-lock-loop bandwidth. As a result of this factor and additive noise, the SNR for the highest frequency channel of the DSB was 22 decibels.

The signal-to-noise ratios for all channels recorded were as follows:

<u>Channel</u> <u>(1 kHz bandwidth)</u>	<u>SNR, db</u>	<u>Channel</u> <u>(1 kHz bandwidth)</u>	<u>SNR, db</u>
1	29	11	24
2	29	12	24
3	28	13	24
4	28	14	23
5	28	15	23
6	27	16	23
7	26	17	22
8	26	18	23
9	25	19	22
10	25	20	22

If there is excessive flutter, the phase-lock loop can momentarily lose synchronization and realign with 180° ambiguity, resulting in a polarity reversal of the data signal. The channel comparator circuit then senses the reversal and reverses it again, which gives traces similar to those shown in figures 6(a) and 6(b). When a tape-drop-out occurs, it affects the channel pilot tone more than the master pilot tone, since a drop-out affects higher frequencies more than lower frequencies.

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<sup>1</sup>F. J. Schmitt, "Double sideband suppressed carrier telemetry system," International Telemetry Conference Proceedings, pp. 347-360.

Inasmuch as the comparison circuit is an amplitude sensing comparison circuit, it senses the drop-out as an out-of-phase condition. As a result, a tape drop-out causes a momentary phase reversal. Therefore, it is important to use high-quality tape with low drop-out characteristics.

Tests to investigate the improvement of the signal-to-noise ratio when a 500 Hz output filter was installed in place of the 1 kHz output filter showed an improvement of 6 decibels. This filter, however, limits the channel bandwidth to 500 Hz.

## ENVIRONMENTAL CONDITIONS

The DSB airborne system was environmentally tested to simulate expected flight conditions in accordance with modified MIL-D-5272, paragraph 14.

Vibration. — Deterioration of the airborne system and its performance during or after subjecting it to a vibration of 10 g was not detected. No failures were observed as a result of these tests. The sinusoidal vibration from 10 Hz to 2000 Hz is likely to be more severe than that which will be experienced in flight.

Temperature. — The linearity of the airborne system was investigated when the system was subjected to temperatures from  $-4^{\circ}\text{F}$  to  $160^{\circ}\text{F}$ . Figures 7 to 11 are plots of the typical accuracies that were experienced for each type of airborne channel tested for static linearity. These plots show that each channel falls within an error band of 2 percent of full scale.

## FLIGHT TESTING

After the laboratory testing was completed, the system was flight tested in a T-33 and an F-111 aircraft. All flight data were acquired on 1 kHz bandwidth channels.

T-33 Flights. — A preliminary flight test was performed using a 20-channel 1 kHz data bandwidth DSB system with known dc level inputs on 18 of the 20 channels. The system was installed in a telemetry pod attached to a T-33 airplane with data radiated by a standard VHF telemetry transmitter. Channel signal-to-noise ratio was measured directly at the ground-station DSB demodulator's output. These values were based on a full-scale dc input of  $\pm 2.5$  volts and  $\pm 10$  millivolts. The millivolt channels were amplified to  $\pm 2.5$  volts in the telemetry pod before application to the DSB system to simulate actual signal conditioning in an aircraft. The average signal-to-noise ratios for the  $\pm 2.5$  volt inputs were in the 36 decibel to 38 decibel range, whereas the  $\pm 10$  millivolt inputs were in the 33 decibel to 35 decibel range.

F-111 Flights. — The F-111 airborne system consisted of two DSB airborne units recorded on an analog tape recorder. For the DSB system data flights on the F-111 airplane, the ground-station demodulators were set up for a  $\pm 5$  volt dc output to correspond to a  $\pm 2.5$  volt dc airborne-unit input. Data on both DSB units were obtained from rake pressure transducers installed for engine-inlet performance studies. The transducer outputs were filtered with 200 Hz, 3-pole, low-pass filters and amplified to  $\pm 2.5$  volts dc for full pressure range before application to the DSB system. Measurement of channels that approached full scale during flight indicated signal-to-noise ratios comparable to those shown in the table on page 3. Preflight corrected ambient-pressure readings taken on the flight tape recorder varied about 4 percent (28 db SNR), as expected. The average value of each channel for the preflight and postflight tests, however, agreed within 1 percent.

## PREFLIGHT SETUP AND ADJUSTMENT

Airborne System.— The airborne system was tested for stability and was found to hold its settings for longer than a week with no more than 1 percent error due to drift on any channel. Thus, only a minimum of preflight procedures are required.

Ground-Station System.— The ground station should be checked regularly for drift of the channel voltage controlled oscillator (VCO), Schmitt trigger, and phase-lock loop. This procedure requires about 1 hour and should be accomplished within 24 hours before flight to assure the desired accuracy.

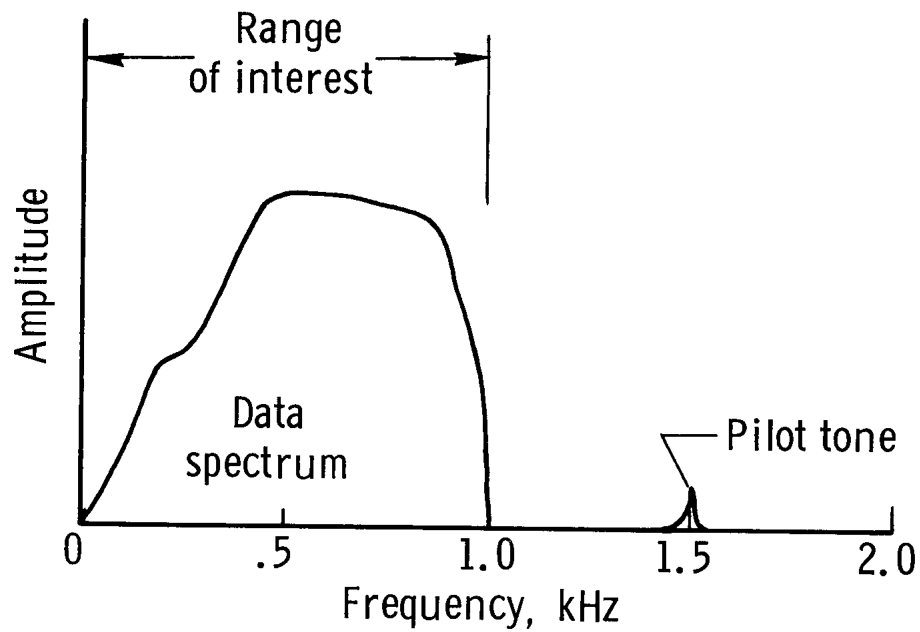
To calibrate this system before flight, a system simulator that simulates each channel is used. This unit gives the proper pilot tones and simulated data signals. In addition, it is recommended that a hangar preflight tape or RF link be used to verify the adjustments of the ground station because of variances in tape recorders and airborne unit settings.

## CONCLUSIONS

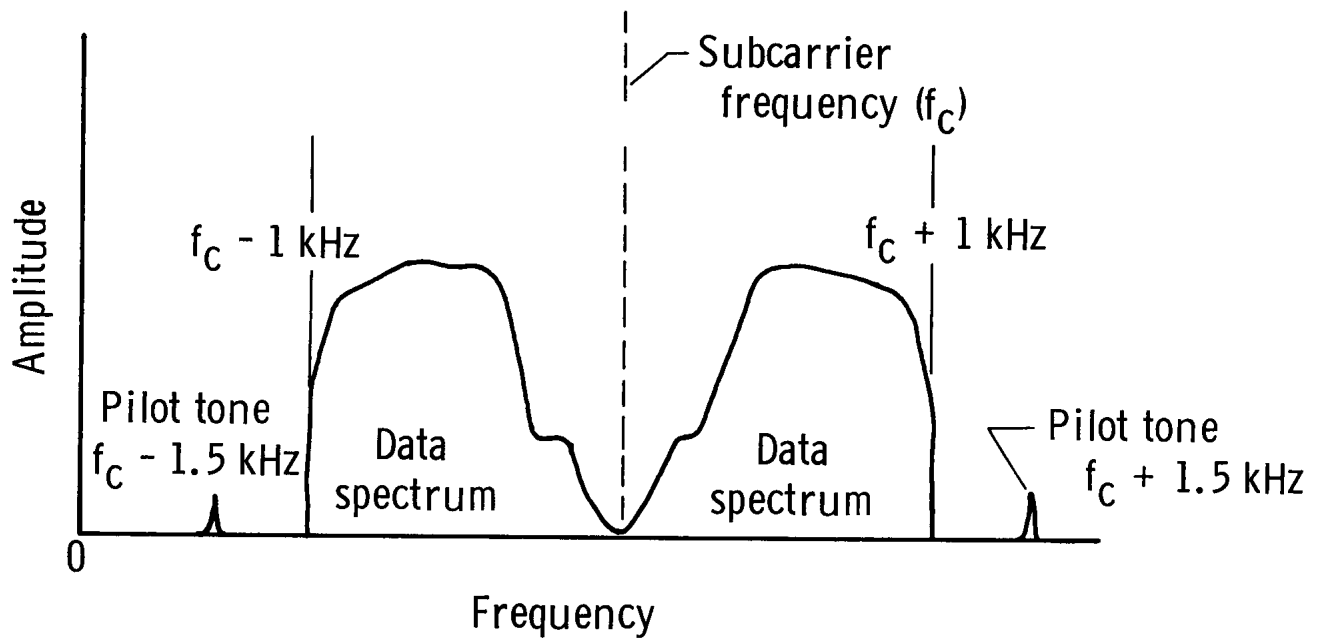
Flight tests of a double sideband FM telemetry system in a T-33 airplane showed that the signal-to-noise ratio for transmitted data was between 39 decibels and 37 decibels below a full-scale signal, whereas the noise from a tape-recorded data link was between 22 decibels at the higher subcarrier frequency and 29 decibels at the lower subcarrier frequency when an analog airborne recorder was used. When a tape recorder was used in the FM recording mode, the signal-to-noise ratios were between 37 decibels and 39 decibels.

The output filter of this system is a 1 kHz low-pass filter. If data that are to be obtained are below 1 kHz, a lower cutoff low-pass filter can be installed that will improve the signal-to-noise ratios. The system, when used with an RF link, operates within a  $\pm 1.5$  percent total accuracy on most channels and no greater than  $\pm 2.5$  percent on any channel. The same accuracy can be expected when the signals are tape-recorded on an FM type magnetic-tape recorder.

Verification of ground-station settings before flight is recommended by use of an RF link or preflight recorder tape.



(a) Before modulation.



(b) After modulation.

Figure 1. – Spectrum occupancy showing data and pilot tone that are translated from analog information to the sidebands of the subcarrier frequencies.



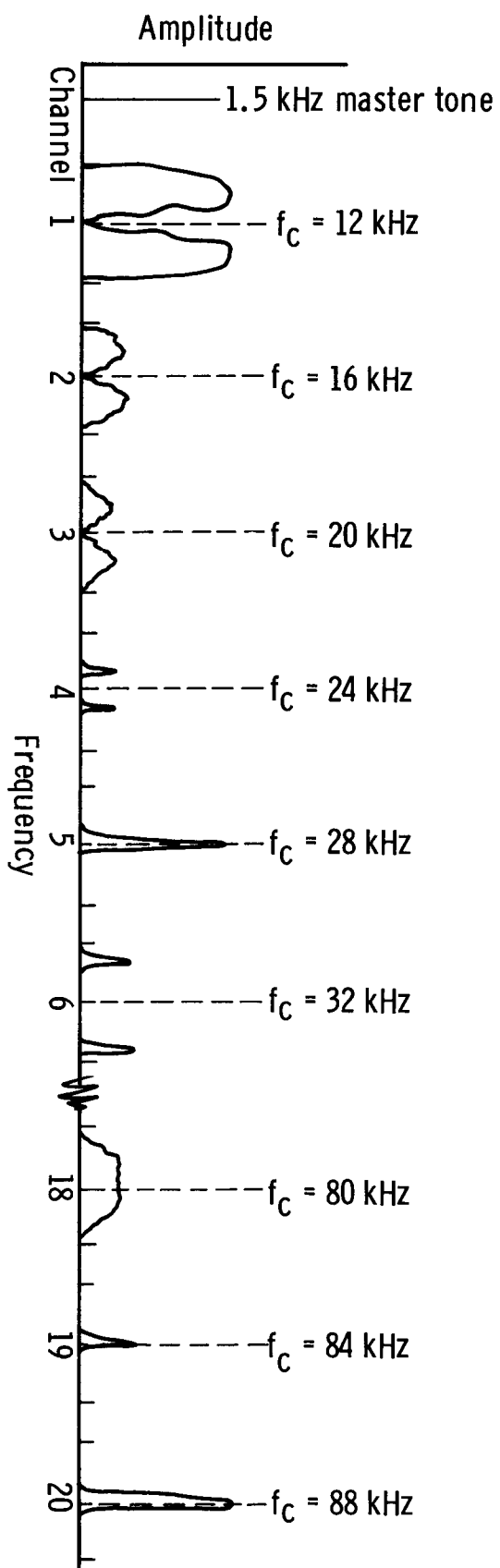
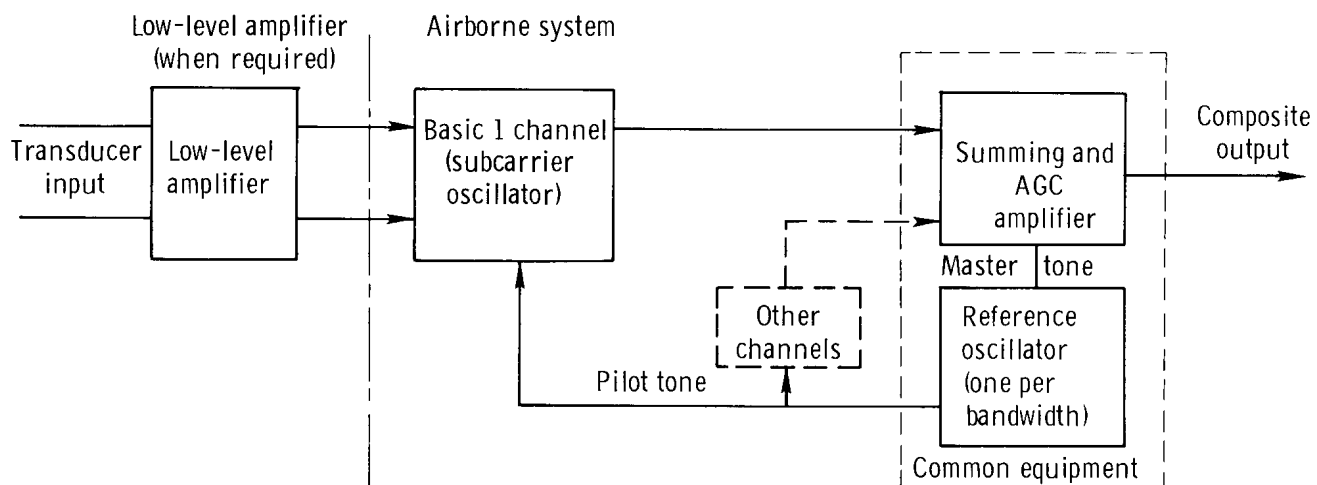
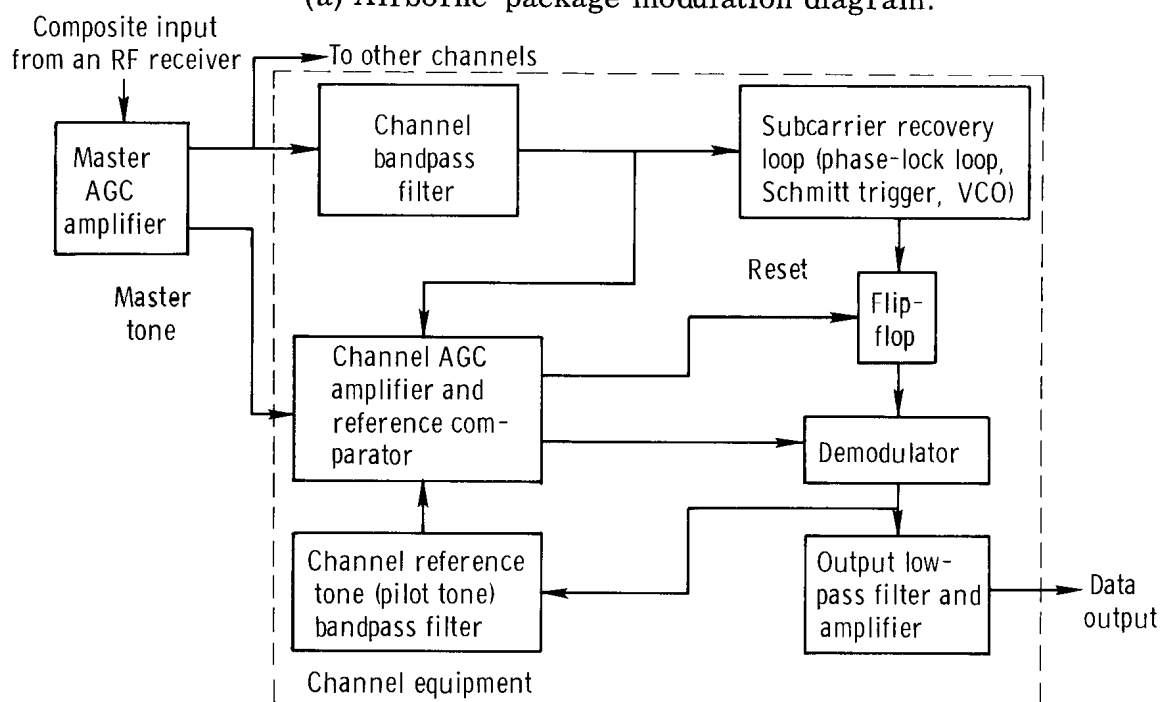


Figure 2. – DSB spectrum utilizing 1 kHz bandwidth channel showing data, pilot tones, and master tone.



(a) Airborne-package modulation diagram.



(b) Ground-station demodulation diagram.

Figure 3. — Block diagram of the DSB system.

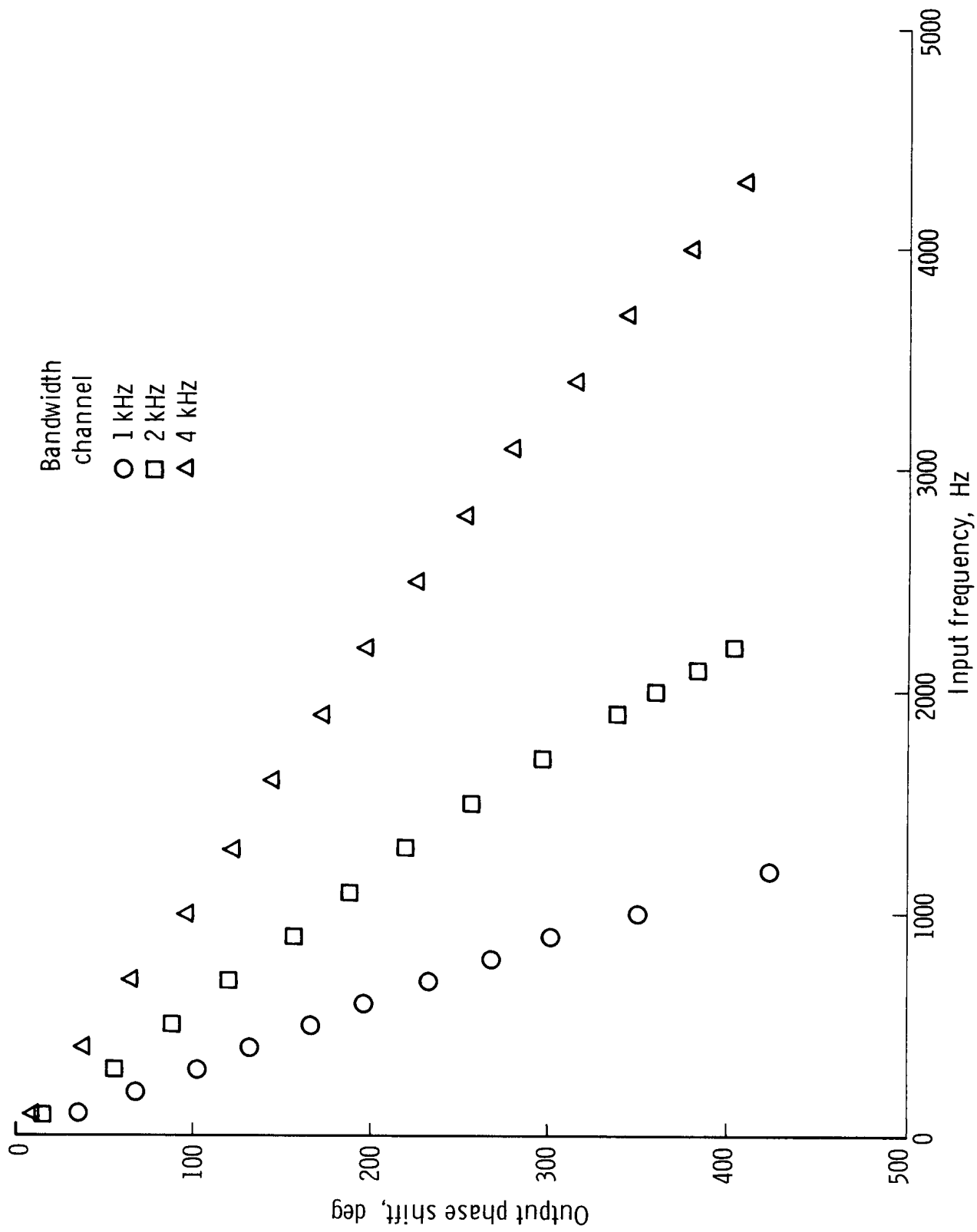


Figure 4. – Phase shift of DSB system.

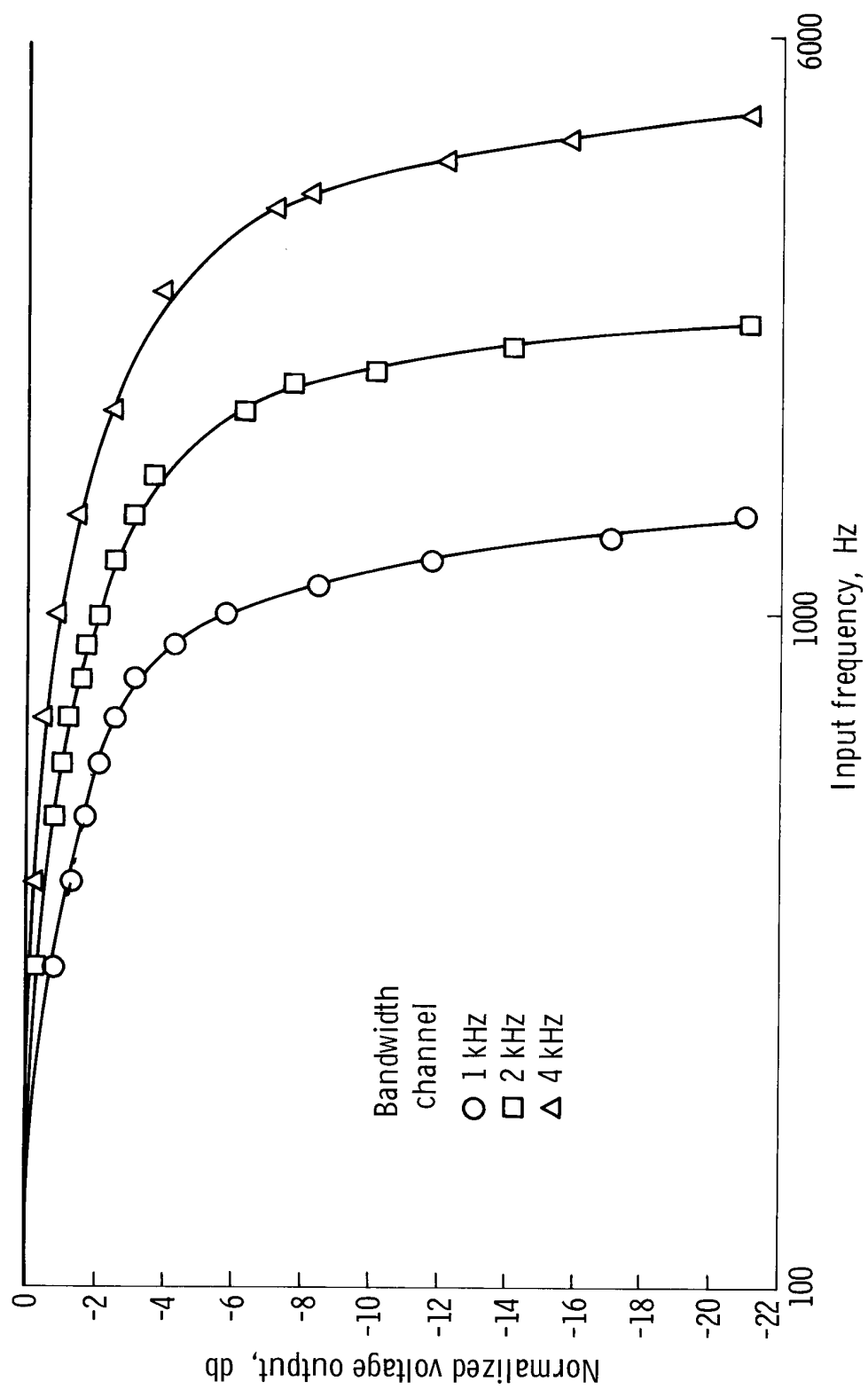
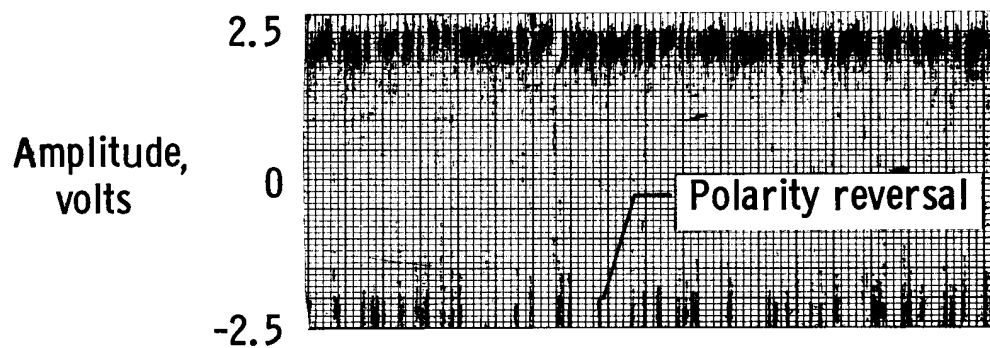
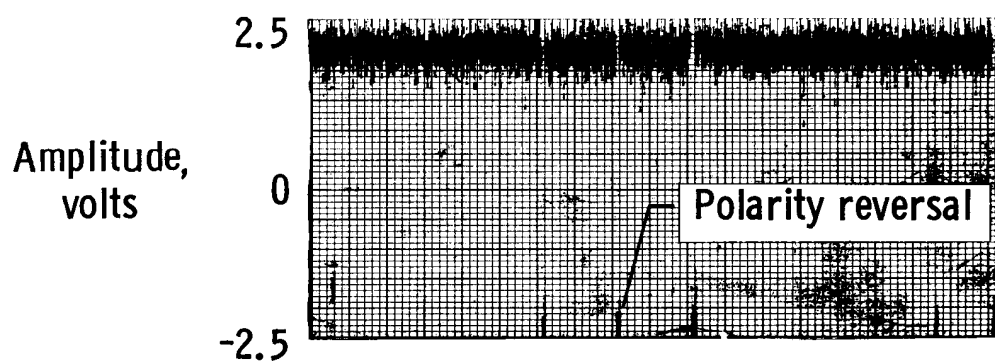


Figure 5. — Output-filter characteristics of DSB ground-station channel bandwidth.



(a) 84 kHz channel.



(b) 60 kHz channel.

Figure 6.— Sanborn recorder record showing polarity reversals caused by the higher frequency channels being unable to hold phase-lock loop resulting from tape flutter.

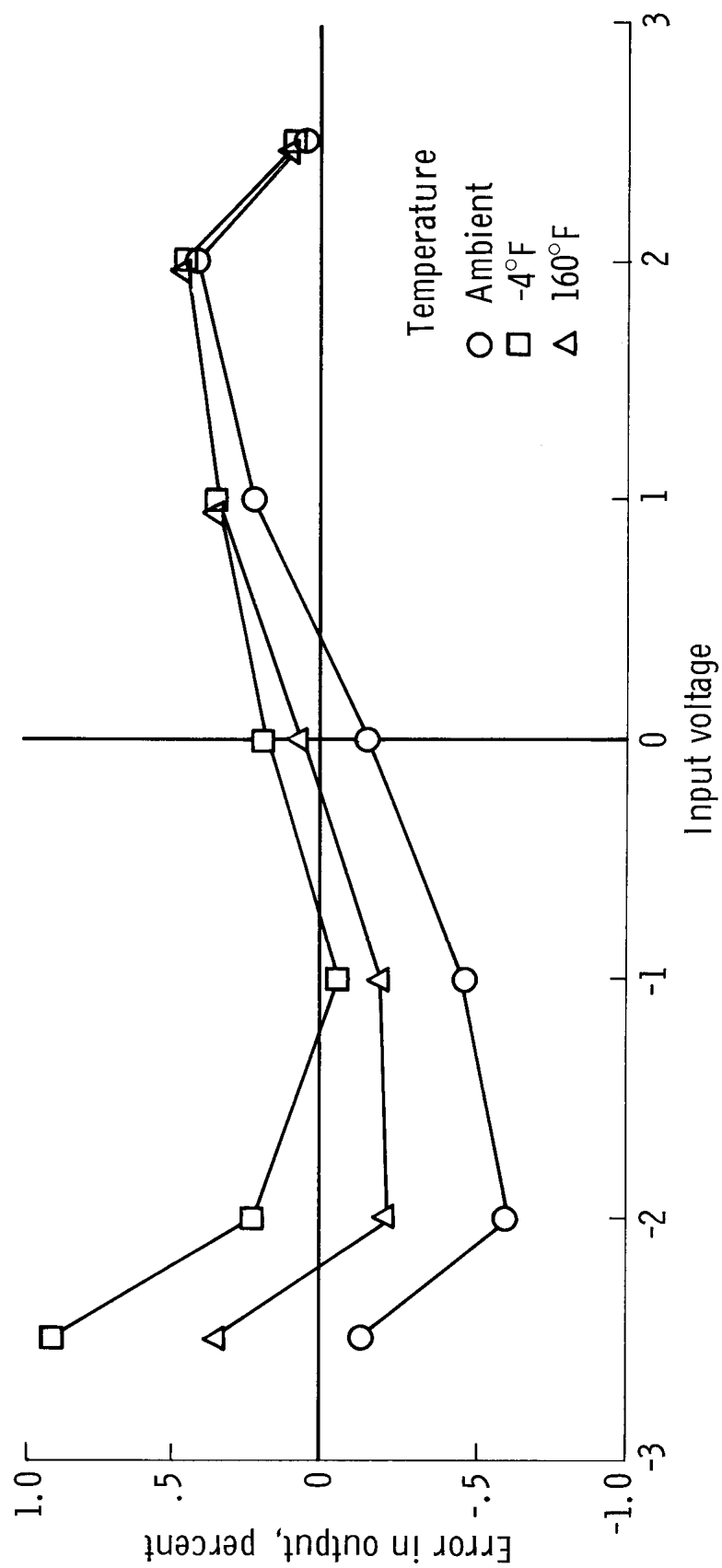


Figure 7. — Double sideband static linearity (typical deviation). 1 kHz channel;  
center frequency, 32 kHz.

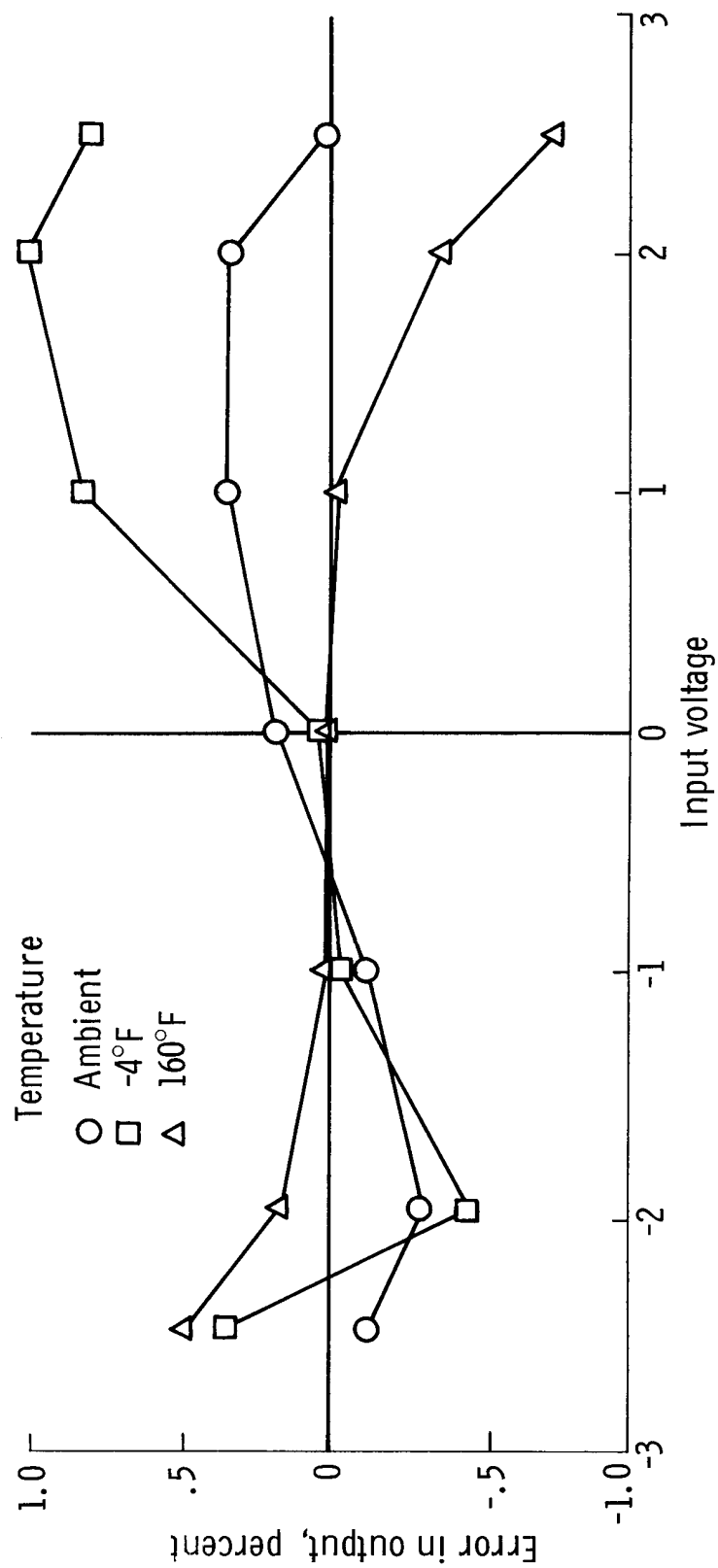


Figure 8. - Double sideband static linearity (largest deviation). 1 kHz channel; center frequency, 48 kHz.

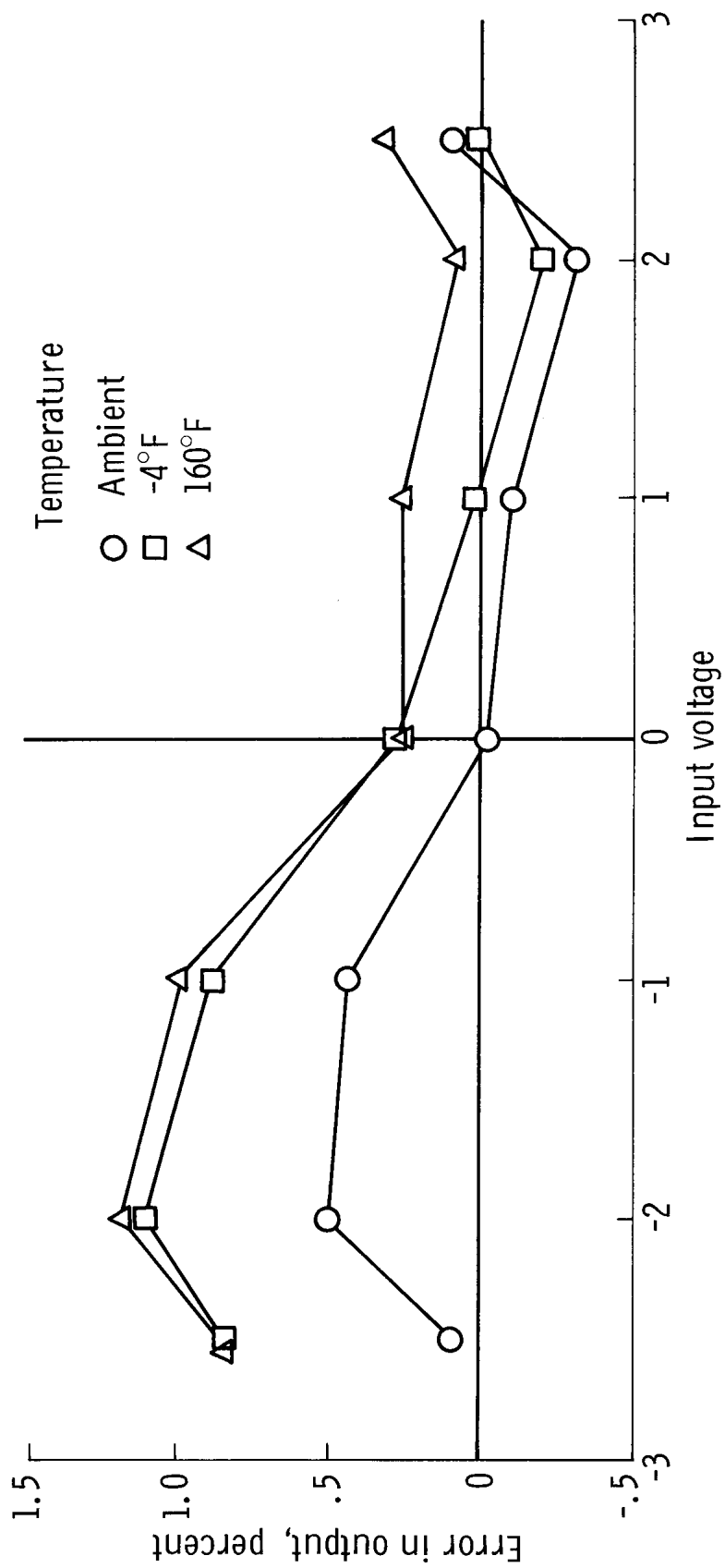


Figure 9.— Double sideband static linearity (average deviation). 2 kHz channel;  
center frequency, 16 kHz.



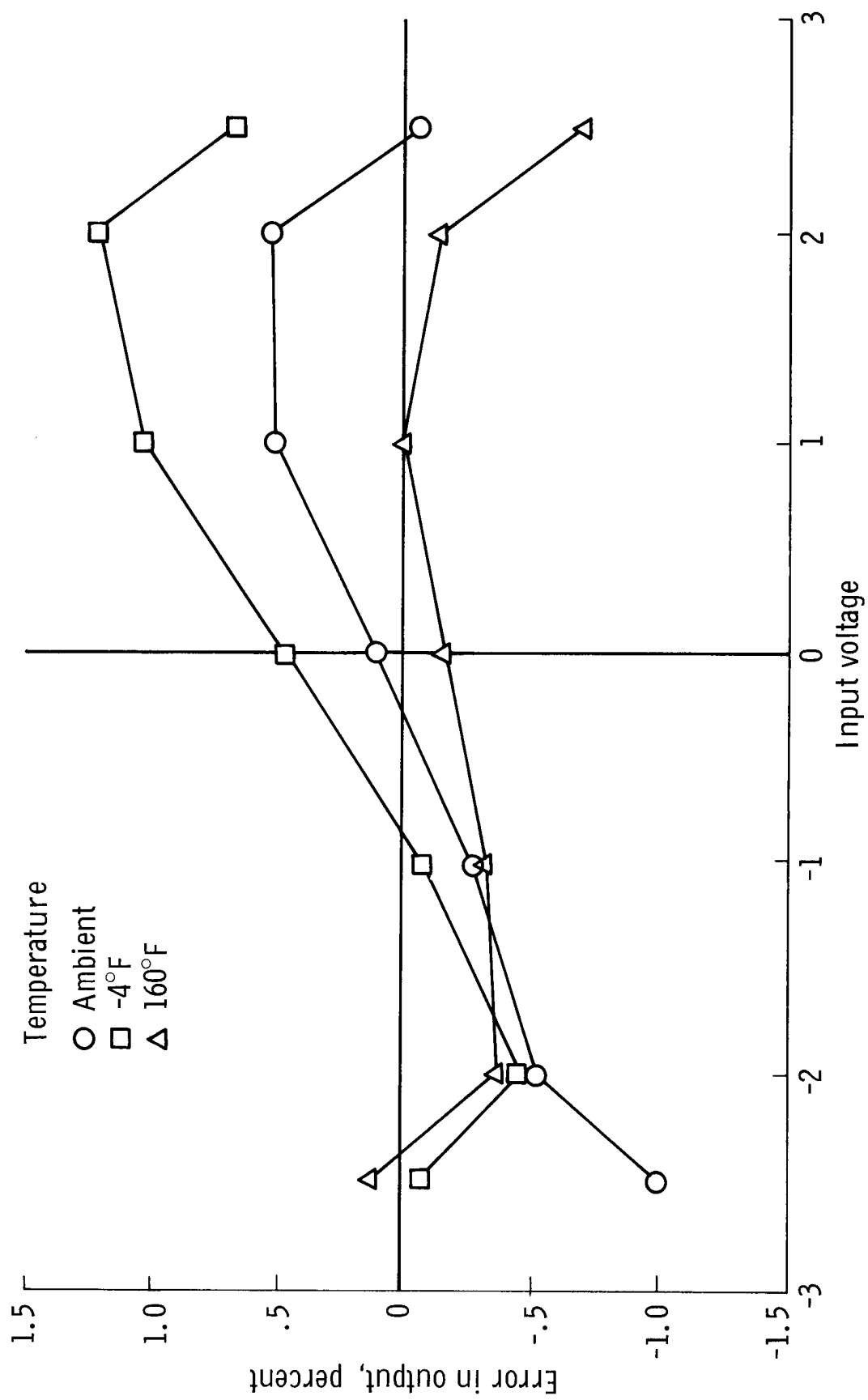


Figure 10. - Double sideband static linearity (largest deviation). 2 kHz channel; center frequency, 64 kHz.

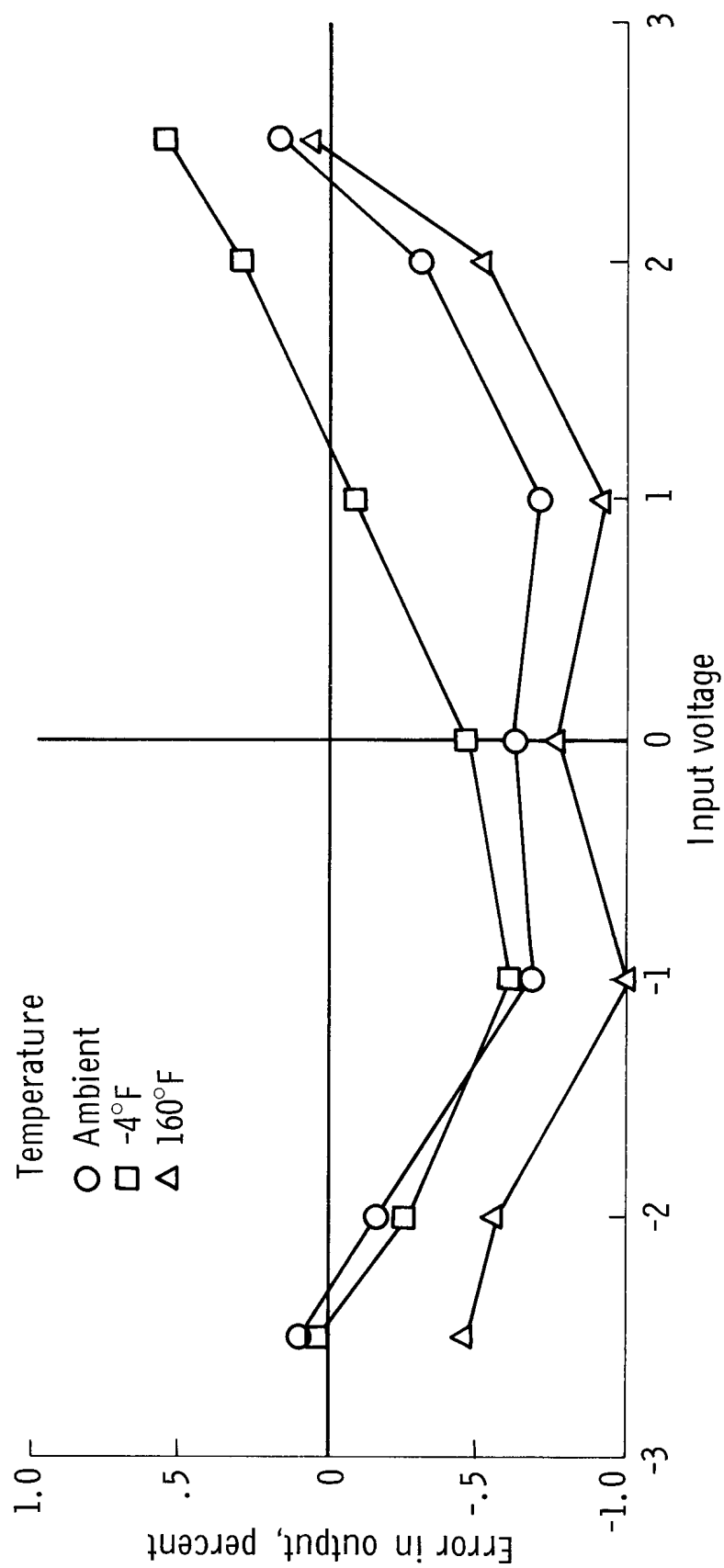


Figure 11. – Double sideband static linearity (typical deviation). 4 kHz channel;  
center frequency, 64 kHz.